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ANALYSIS of the LOSSES
IN A
STEAM ENGINE
BY THE METHODS OF
HIRN AND REEVE

W B Goentner

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"Heat distribution in a steam-engine
by the methods of Hirn and Reeve."

The test of a steam engine, when at all complete, always aims at the determination of not only how much the engine falls short of perfect efficiency, but also why it does so. Of the heat which we entrust to it for conversion into work, we demand an account. If the account returned is to be of any value to us, it must be itemized. When it becomes itemized, then, from the results obtained, we can make such improvements and adjustments in the engine, that will increase its efficiency.

In every engine, no matter how well it be constructed, there are losses due to the inefficiency of the cycle, which cannot be helped. Again, there are losses due to the inefficiency of the machine,

S., M.B.
20 May '98. Sr. T. Course.

which can be helped; and it is these losses which a steam engine analysis seeks to itemize, and if possible, prevent.

There are two methods in use. The analysis of Hirn, an analytic method; and the analysis of Reeve, a graphic method. The object of this thesis is to determine the various losses in a particular engine, by each of these methods, and to make a comparison of the results obtained, in order to determine which method is the more desirable.

Hirn's analysis may be briefly described as follows: The amount of heat supplied an engine may be determined by measuring the pressure, quality, and weight of the steam, used by the engine. That removed, by measuring the heat in the condensed steam, and that given to the condensing

water. The difference between these gives the amount of heat to be accounted for, by the engine. A part of this is transformed into external work, which may be measured from the indicator card; and the rest goes to make up the various losses. A part of these losses may be due to leaks, which may be very easily remedied; but the rest is due to the difference in temperature between the steam and the cylinder walls. The heat given to the walls during any part of the stroke may be found as follows: Between any two positions of the piston, the quantity of heat which has done external work, and that which is exchanged between the metal and the steam, form a sum equal to the difference between the amount of heat in the steam in those

positions; increased, if necessary, by the heat which may have been introduced with new steam, or diminished by that which may have left the cylinder. This gives rise to the equation,

Heat in steam at beginning + Heat from boiler
= Heat in steam at end + External work
+ Heat given to the walls.

As is understood from Thermodynamics, the heat in the steam at any point may be represented by $M(q + xp)$, and the heat entering from the boiler by $M_1(q_1 + x_1 r_1)$ if moist, or by $M_1[q_1 + r_1 + .48(t_{sup} - t_{sat})]$, if superheated. These letters have the same meaning as in Peabody's Tables, from which all data, used in this thesis, relative to the properties of steam, are taken. The above equation then becomes

$$m(q_0 + x_0 p_0) + M(q + xr) = (m + M)(q_1 + x_1 p_1) + \text{work} + \text{heat lost.}$$

Such an equation may be obtained for any part of the stroke, and the losses at different parts calculated. The amount of heat remaining in the cylinder at any point after cut off may be calculated from the indicator diagram. This multiplied by the known weight gives the total heat. Then the heat supplied to the engine, plus the heat in the clearance spaces, gives the total heat available. The following equations represent the losses at different parts of the stroke.

Loss during admission =

Heat supplied + clearance heat

$-$ (heat at cut off + work during admission)

Loss during expansion =

Heat at cut off

$-$ (heat at release + work during expansion)

Loss during exhaust =

Heat at release + work during exhaust

− (heat at compression + heat given to condensing water + heat in condensed steam).

Loss during compression =

Heat at compression + work during compression − heat at admission, or clearance heat.

To obtain the amount of steam in the clearance spaces, it was assumed to be safe to consider $x = 1.00$ at the beginning of compression. For a more complete description of this method, one is referred to Peabody's Thermodynamics, or to Carpenter's Experimental Engineering.

The other method by Reeve, is far more convenient. It involves the construction of an entropy - temper-

ature diagram from the indicator card. This analysis depends on the fact that the steam in the cylinder may be regarded as consisting of two separate portions. One portion, the "cushion steam" remains always in the cylinder, expanding and contracting, as the piston goes and returns. It acts like a spring, attached to the cylinder head, and constitutes in every respect a part of the engine's mechanism. The other, the "cylinder feed" is that portion supplied from the boiler for the performance of each stroke, and from which all losses must be made good. The amount of cylinder feed is known when the water rate has been determined. What becomes of it may be determined by means of the indicator card, and the entropy-

temperature diagram. An entropy temperature diagram is shown at the end of the thesis. For a description of its construction, one is referred to a pamphlet by Reeve, entitled, "The entropy-temperature analysis of steam-engine efficiencies." Reeve also gives a very good conception of entropy in this pamphlet.

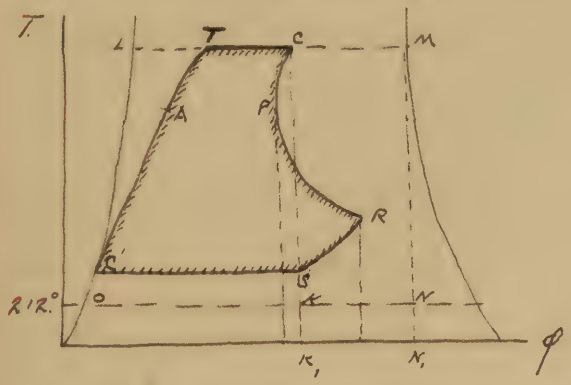
In order to utilize the diagram, it is necessary to possess accurate information concerning

(1) Size of cylinder, and speed of engine.
(2) Water rate per I H P hour
(3) Clearance volumes,
(4) An average indicator card.

This latter should be very carefully chosen, or what is better, manufactured because much of the accuracy of the analysis depends on this.

This card is reproduced on the diagram, with a curve corresponding to the weight of cushion steam per lb. of cylinder feed as a co-ordinate axis instead of the usual vertical axis. This makes an indicator card showing the volume and pressure of the cylinder feed alone, instead of the volume of the total steam in the cylinder. From a graphical construction explained in Reeve, the entropy temperature diagram is then obtained. It is the nature of this diagram, that its area represents heat. Then by comparing this diagram, with the diagram of a theoretically perfect engine, we can measure the deficiency in area, as the loss in heat. The shape of the diagram shows one at a glance just where the greatest losses occur.

The diagram, as constructed by Reeve is for one lb. of steam, and consequently represent losses per lb.



A = admission
C = cut off.
R = release
C' = compression

In this diagram it is seen that abscissae are isothermals, and ordinates adiabatics. The diagram for a perfect steam engine would be LMNO, ON being the isothermal corresponding to atmospheric pressure. It is seen that the actual diagram falls short of this. From Reeve's discussion, one may see that if it were not for initial condensation, the point of cut off C, would occur at M. The loss of entropy CM multiplied by the absolute temper-

ature at C, is the loss of heat due to initial condensation. It is represented by the area C M K N down to the absolute zero of temperature. If the expansion were adiabatic from this point, the diagram would follow the line C K, but there is still a loss due to "condensation during expansion". This is represented by the area under C P. From the point P onward, heat is given to the steam by the cylinder walls, and re-evaporation takes place. This is again and is represented by the area under P R. If the expansion were complete, R would be on the back pressure line, but as the valve opens before the pressure is sufficiently reduced, there is a further loss represented by the area under R S, due to "incomplete expansion". The loss C' L T is due to clearance.

Tests were made for these analyses on a 20 HP Hamilton Corliss engine, built by the Hooven, Owens, and Rentsch Co Company, of Hamilton, Ohio. This engine is similar to the ordinary Corliss engine, and was of the following dimensions;

Diam. of cylinder	$10\frac{3}{16}$ ins.
Length of stroke	24 ins.

Diam of piston rod		2 ins
Clearance,	Head	6.04 %
	Crank	5.28 %.

Before any tests were made, the engine was put in as good condition as possible. All stuffing boxes were repacked, and all leaky gaskets replaced. Oil cups and lubricator were made to work properly. The dash pots were out of order, and were thoroughly overhauled.

The valves were set by taking indicator cards. At first, they were considerably out, as the engine took all the steam on one end. Since the test was not for efficiency, it did not matter very much at what point compression took place, so the links were so adjusted, to give the lengths of compression and exhaust, equal on

each end. The admission lines were so adjusted, that admission did not take place too late. The governor lines were then adjusted to give equal cut off on each end. The values were assumed to be correct when the following card was obtained

It was decided to run one test condensing and one non-condensing. The exhaust from the engine was carried to a Wheeler surface condenser. A Blake pump was attached to the condenser, but was practically useless. Several

days were spent in overhauling it. The piston rings on the air end were adjusted to give the highest vacuum possible. The valves and valve seats were all reseraped and the valves set.

To make a Hirn's or Reeve's analysis, a complete engine test is required. The load should be kept constant, and the condensing water weighed, and its temperature measured, both when flowing into and out from the condenser. The quality of the steam supplied to an engine should be measured.

The load on the engine was measured by a Prony brake, as shown in the photograph. The speed was measured by a continuous counter, attached to the shaft. The discharge from the air pump was pumped into tanks and weighed. The condensing water was

measured by a weir. The quality of the steam was measured by a Barnes calorimeter, with a drip pot and condenser attached. The calorimeter was well lagged to prevent radiation. Only one indicator was used, it being connected to either end of the cylinder by a three way cock. The reducing motion is of the ordinary reducing pulley type, the cord from the cross head being attached to a large pulley, and the cord from the indicator to a smaller pulley. These pulleys, or drums, are on different spindles connected by a pair of gear wheels, which make the reduction still greater.

Instruments used.

Thompson Indicator, no 3071.

40# Spring, no 3260.

Williamson and Cassidy Gauge, no 18943?

Bourdon Vacuum Gauge, no 7103.

Schaeffer and Budenberg Revolutive Counter

Six thermometers

Manometer, or Hg. column,

Hook Gauge

Three Richle Platform scales

One small Fairbanks scales.

Planimeter.

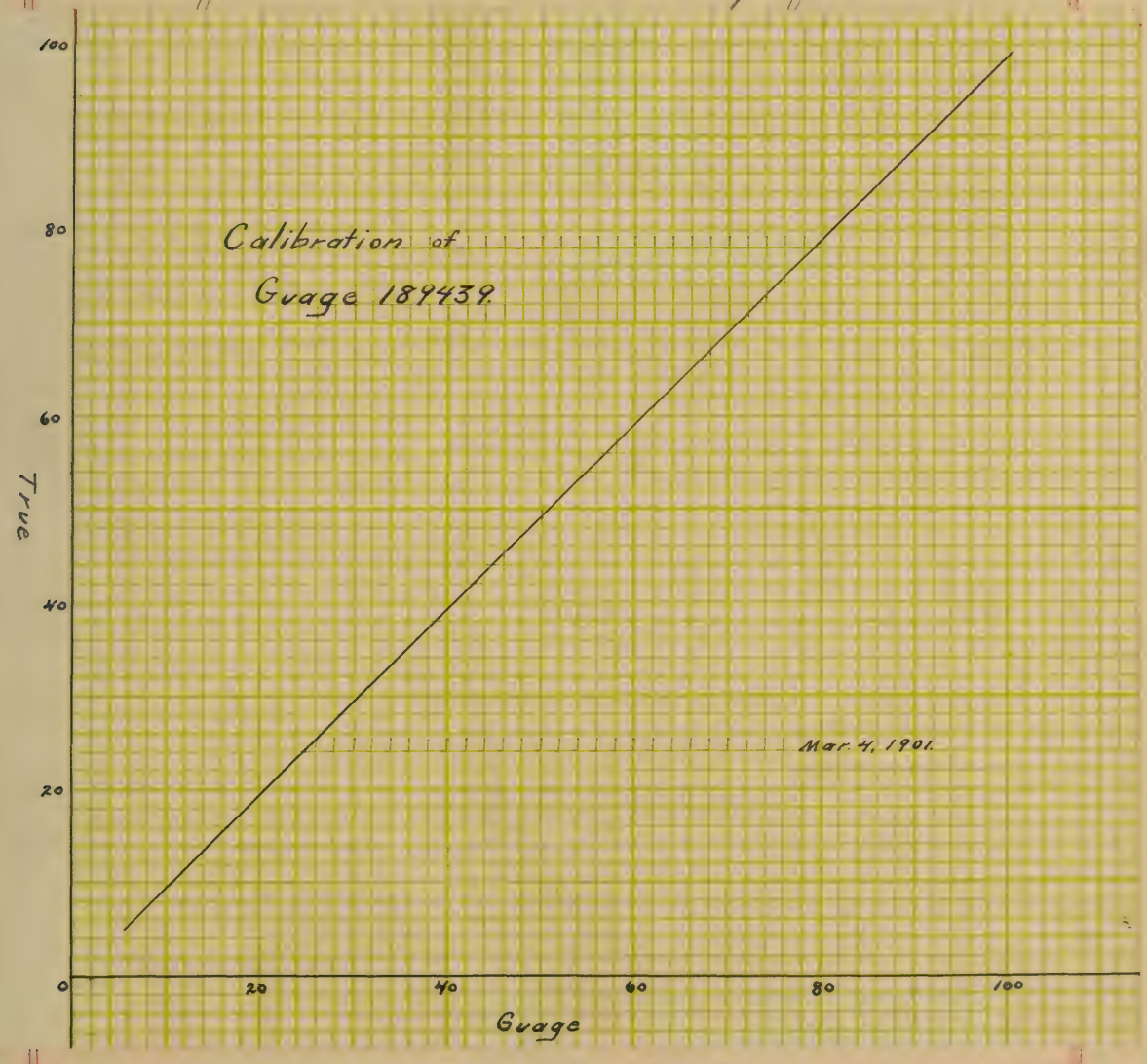
Calibration of instruments.

The reducing motion of the indicator was calibrated on Mar 4, by dividing the stroke into a number of equal parts, and setting the cross head at these marks; the corresponding point was then marked on the indicator. The motion was found to be correct, and the cards obtained are shown below.

Calibration - Reducing Motion.

The indicator spring was tested in the usual way, by comparing it with a steam guage, on the spring tester. Three cards, both ascending and descending, were obtained, the results of which follow.

Guage used 189439. see page 20.



Calibration of 40" Indicator Spring no 3260.

Ascending

Gauge	True	lbs diff	ins. diff	Scale.	ins. diff	Scale	ins. diff	Scale.
			*1		*2		*3	
10	9.8							
20	19.7	9.9	.23	43.1	.23	43.1	.24	41.3
30	29.8	10.1	.25	40.4	.25	40.4	.24	42.1
40	39.9	10.1	.26	38.8	.25	40.4	.25	40.4
50	49.2	9.3	.24	38.7	.23	40.4	.24	38.7
60	58.5	9.3	.23	40.4	.23	40.4	.22	42.3
70	69.0	10.5	.27	38.9	.29	36.2	.28	37.5
80	79.5	10.5	.26	40.4	.26	40.4	.27	38.9
90	89.6	10.1	.26	38.8	.25	40.4	.26	38.8
Sums				319.5		321.7		320.0
Mean.				39.94		40.21		40.00

Descending

10	9.0							
20	19.0	10.0	.23	43.5	.25	40.0	.25	40.0
30	28.9	9.9	.24	41.3	.25	39.6	.25	39.6
40	39.0	10.1	.25	40.4	.26	38.8	.24	42.1
50	48.9	9.9	.23	43.1	.24	41.3	.23	43.1
60	58.1	9.2	.25	36.8	.23	40.0	.26	35.4
70	68.4	10.3	.25	41.2	.27	38.2	.23	44.8
80	79.2	10.8	.26	41.5	.25	43.2	.28	38.6
90	89.3	10.1	.26	38.8	.26	38.8	.26	38.8
Sums				326.6		319.9		322.4
Mean.				40.83		39.99		40.30

Ascending

39.94
40.21
40.00
3) 120.15
40.05

Descending

40.83
39.99
40.30
3) 121.12
40.37

40.05
40.37
2) 80.42
Scale = 40.21

Calibration of Guage 189439.

Time	Ascend.	Descend.
10	10.2	11.0
20	20.3	21.0
30	30.2	31.1
40	40.1	41.0
50	50.8	51.1
60	61.5	61.9
70	71.0	71.6
80	80.5	80.8
90	90.4	90.7

The steam guage used in the regular tests was no 189437. It was placed on the calorimeter, and was calibrated immediately after each test on a Crosby Guage Tester.

Calibration of Guage 189437.

	Time	Ascend.	Descend.	Mean.
Apr. 1,	80	83.3	84.7	84.0
	85	88.0	89.5	88.7
	90	93.3	94.3	93.8
	95	98.1	99.5	98.8
	100	103.0	104.4	103.7
	105	108.0	109.6	108.8
	110	113.8	115.0	114.4
	115	119.2	120.0	119.6
May 13,	80	81.7	81.7	81.7
	85	87.9	89.3	88.6
	90	92.8	94.2	93.5
	95	97.5	99.4	98.4
	100	102.8	104.5	103.7

The vacuum guage was calibrated by comparing it with a mercury column, both being attached to the same condenser.

Owing to lack of time, the clearance volumes of the engine were not measured. The results of Messrs. Deacon and Wise, '98, were taken as correct.

Each test was run for one hour, general readings being taken every five minutes, by J. M. Mains, 3rd. Water and speed readings were taken every 15 minutes. Each test was worked up as a general test, before the analyses were made, that is, the water rate, and I.H.P. were determined. For the Reeve analysis, a mean card was obtained.

Test no 1. Condensing. April 1, 1901.

Observations.

Time	Condenser. Temperatures: Con. Steam	Inflow	Outflow	Vacuum	Hook Gage	Temp at weir	Calorimeter: Pressure	Upper Ther.	Lower Ther.	Hg. Column: Left	Rt.
1.05	118	80	101	12.0	10.97	101	93	324	284	2.70	7.15
1.10	118	81	102	12.0	10.98	100	92.5	323	284	2.70	7.15
1.15	118	82	102	12.0	10.95	100	93	324	284	2.70	7.15
1.20	119	82	103	11.7	10.95	101	93	322	284	2.70	7.15
1.25	119	83	104	11.7	10.95	100	93	322	284	2.70	7.15
1.30	118	84	104	11.7	10.95	101	93	322	284	2.70	7.15
1.35	119	84	—	12.6	10.95	—	95	324	285	2.65	7.20
1.40	119	84	—	12.7	10.95	—	95	325	285	2.65	7.20
1.45	120	86	105	13.0	10.95	102	97	326	286	2.55	7.30
1.50	120	86	106	13.4	10.95	104	98	327	284	2.50	7.35
1.55	120	87	107	13.4	10.95	103	98	328	284	2.50	7.30
2.00	121	88	107	13.4	10.95	105	97	327	284	2.60	7.25
2.05	122	88	108	13.1	10.95	107	95	326	283	2.60	7.25
Sums	1551	1095	1149	1627	14230	1124	1232.5	4220	3695	34.25	93.95
Means	119.3	84.2	104.5	13.52	10.946	102.2	94.8	324.6	284.2	2.63	7.21

Condensed Steam: Time	Ht. empty	Ht full	Can at drip pot: Time mk.	Ht emp.	Ht. full	Buescat: Time	Ht emp	Ht. full	Counter: Time	Reading
1.05	24.5	384.0	1.05	1-10-2	1-15-8	1.05	3-3-5	21-5-8	1.05	82372
1.20	95.0	224.0	—	1-7-0	1-11-12	1.23	2-13-14	22-1-14	1.10	82673
1.35	222.0	368.5	2.05			1.42	3-3-6	20-11-2	1.30	83872
1.50	80.0	224.0				1.58	2-13-9	9-13-12	1.35	84172
2.05						2.05			1.50	85074
									2.05	85976
Totals	639.5	1200.5		3-1-2	3-11-4		12-2-2	74-0-4		
Diff		561.0			0-10-2			61-14-2		3604

Brake reading - 95.9# Zero 107# Diff = 95.2#

Zero reading of hook gauge = 12.89"

Zero reading of Hg. Column Left 4.80" Right 5.85"

Barometer 29.96 ins

Cards were taken every five minutes

Preliminary Horse and Cardo.

No.	Area		Length	M. E. P.	
	Head	Crank		Head	Crank
1	2.17	2.63	3.33	26.2	31.8
2	2.03	2.39	3.32	24.6	28.9
3	2.09	2.55	3.33	25.3	30.8
4	2.12	2.61	3.34	25.5	31.4
5	2.18	2.43	3.34	26.2	29.3
6	2.15	2.41	3.35	25.8	28.9
7	2.21	2.59	3.34	26.6	31.1
8	2.00	2.52	3.34	24.1	30.3
9	2.00	2.50	3.32	24.2	30.3
10	1.94	2.31	3.34	23.4	27.8
11	2.05	2.39	3.34	24.7	28.7
12	2.05	2.47	3.34	24.7	29.7
			40.03	301.3	359.0
			3.336	25.11	29.92

Mean values of cut off, etc.

No.	Ordinates								Abscissae					
	Admission		Cut-off		Release		Compression		Cut off		Release		Compression	
	H	C	H	C	H	C	H	C	H	C	H	C	H	C
1	1.45	1.42	2.58	2.60	.47	.50	.24	.24	.23	.31	3.12	3.17	.32	.31
2	1.45	1.44	2.52	2.60	.44	.47	.23	.23	.19	.24	3.14	3.15	.33	.32
3	1.45	1.37	2.55	2.59	.44	.49	.21	.21	.20	.26	3.11	3.09	.35	.32
4	1.40	1.42	2.53	2.61	.46	.50	.23	.23	.21	.30	3.14	3.16	.35	.35
5	1.43	1.30	2.58	2.59	.47	.48	.23	.23	.26	.26	3.11	3.15	.35	.32
6	1.48	1.10	2.55	2.61	.45	.48	.23	.23	.21	.25	3.16	3.15	.32	.32
7	1.28	1.26	2.60	2.65	.45	.49	.22	.22	.23	.30	3.11	3.17	.29	.34
8	1.26	1.44	2.61	2.68	.43	.49	.22	.22	.14	.25	3.11	3.17	.30	.34
9	1.77	1.38	2.68	2.75	.44	.49	.22	.22	.16	.23	3.09	3.12	.32	.34
10	1.35	1.38	2.68	2.73	.41	.46	.21	.21	.16	.20	3.12	3.16	.30	.31
11	1.40	1.42	2.67	2.73	.43	.46	.21	.21	.18	.23	3.14	3.17	.34	.35
12	1.45	1.30	2.63	2.66	.43	.47	.22	.22	.18	.24	3.13	3.15	.30	.33
Sum	17.17	16.23	31.17	31.80	5.32	5.78	2.67	2.67	2.35	3.07	37.48	37.81	3.87	3.95
Mean	1.431	1.352	2.597	2.650	.443	.482	.223	.223	.196	.256	3.123	3.151	.323	.329
	57.4*	54.3*	104.2	106.5	17.8	19.4	8.96	8.96	5.88%	7.68%	93.8	94.5	9.69	9.86

Measurements for external work.

No	Head						Crank					
	Admission			Expansion			Admission			Expansion		
	R_1	R_2	Area	R_1	R_2	Area	R_1	R_2	Area	R_1	R_2	Area
1	0623	0679	.56	.0679	0917	2.38	8422	8498	.76	0194	0457	2.63
2	1250	1297	.47	1297	1534	2.37	1063	1124	.61	1124	1380	2.56
3	2200	2250	.50	2250	2484	2.34	1699	1768	.69	1768	2027	2.59
4	2547	2599	.52	2599	2837	2.38	2470	2547	.77	2547	2810	2.63
5	3221	3285	.64	3285	3523	2.38	3150	3219	.69	3219	3474	2.55
6	3998	4052	.54	4052	4292	2.40	3685	3748	.63	3733	3980	2.47
7	4902	4959	.57	4959	5197	2.38	4532	4608	.76	4608	4870	2.62
8	5593	5629	.36	5629	5863	2.34	5375	5440	.65	5440	5708	2.68
9	0578	0620	.42	0620	0859	2.39	0146	0211	.65	0211	0470	2.59
10	1380	1425	.45	1425	1653	2.28	1148	1202	.54	1202	1460	2.58
11	2296	2343	.47	2343	2574	2.31	1885	1949	.64	2078	2335	2.57
12	3104	3152	.48	3152	3384	2.32	2853	2919	.66	2919	3177	2.58
			5.98			28.27			8.05			31.05
			.498			2.36			.671			2.587
	Exhaust			Compression			Exhaust			Compression		
1	1160	1220	.60	1220	1238	.18	0459	0522	.63	0522	0539	.17
2	1947	2008	.61	2008	2025	.17	1568	1630	.62	1450	1466	.16
3	2140	2195	.55	2195	2211	.16	1904	1960	.56	1960	1974	.14
4	2841	2901	.60	2901	2918	.17	2659	2722	.63	2722	2738	.16
5	3502	3567	.65	3567	3585	.18	3389	3456	.67	3456	3471	.15
6	4253	4316	.63	4316	4330	.14	4067	4131	.64	4131	4145	.14
7	5148	5208	.60	5208	5221	.13	4915	4975	.60	4975	4992	.17
8	5835	5895	.60	5895	5909	.14	5704	5765	.61	5765	5783	.18
9	0874	0934	.60	0934	0950	.16	0498	0556	.58	0556	0573	.17
10	1713	1767	.54	1767	1781	.14	1398	1457	.59	1469	1483	.14
11	2539	2591	.54	2591	2608	.17	2188	2247	.59	2247	2264	.17
12	3318	3374	.56	3374	3391	.17	3100	3160	.60	3175	3191	.16
			7.08			1.91			7.32			1.91
			.590			.159			.610			.159

Data for mean card.

No	Expansion									Ex Lever		Compression	
	1	2	3	4	5	6	7	8	9	1	2	1	2
Head 1	.48	.50	.55	.60	.67	.77	.93	1.20	1.85	.42	.47	.30	.50
2	.46	.48	.52	.56	.64	.75	.90	1.16	1.78	.40	.45	.32	.50
3	.44	.48	.51	.56	.64	.75	.90	1.17	1.84	.38	.44	.35	.55
4	.46	.49	.52	.57	.65	.75	.91	1.16	1.78	.40	.46	.30	.49
5	.47	.51	.55	.60	.68	.79	.96	1.25	1.99	.43	.47	.33	.52
6	.46	.49	.53	.57	.65	.75	.89	1.17	1.83	.42	.46	.32	.51
7	.45	.48	.52	.57	.65	.75	.90	1.18	1.83	.40	.45	.30	.45
8	.43	.46	.50	.55	.62	.71	.85	1.09	1.60	.35	.42	.29	.48
9	.44	.48	.52	.56	.63	.72	.86	1.11	1.68	.39	.45	.30	.49
10	.42	.45	.48	.53	.59	.68	.82	1.06	1.61	.37	.42	.28	.46
11	.44	.47	.50	.55	.61	.70	.85	1.07	1.67	.40	.44	.28	.50
12	.44	.46	.50	.55	.62	.71	.85	1.14	1.70	.39	.43	.31	.48
Sum	5.39	5.75	6.20	6.77	7.65	8.83	10.62	13.76	21.16	4.75	5.36	3.68	5.93
Mean	.449	.479	.517	.564	.637	.736	.885	1.145	1.763	.396	.449	.307	.494
Crank. 1	2.50	1.48	1.12	.92	.79	.68	.62	.56	.53	.51	.47	.52	.33
2	2.01	1.34	1.04	.84	.72	.63	.57	.52	.49	.48	.43	.48	.29
3	2.10	1.39	1.08	.88	.75	.66	.58	.53	.50	.48	.42	.50	.30
4	2.34	1.45	1.12	.91	.77	.67	.61	.56	.51	.50	.47	.52	.33
5	2.09	1.38	1.05	.85	.74	.65	.58	.53	.50	.48	.44	.50	.32
6	2.09	1.33	1.01	.85	.72	.64	.58	.53	.50	.49	.44	.50	.30
7	2.25	1.42	1.06	.87	.75	.66	.59	.54	.50	.49	.44	.49	.30
8	2.15	1.39	1.06	.88	.75	.65	.60	.55	.51	.50	.46	.54	.31
9	2.08	1.34	1.05	.87	.74	.65	.59	.54	.50	.49	.45	.52	.29
10	1.98	1.30	.99	.81	.70	.62	.56	.52	.49	.48	.43	.49	.29
11	2.08	1.32	1.03	.84	.72	.62	.57	.52	.49	.48	.42	.49	.30
12	2.05	1.36	1.04	.85	.72	.64	.58	.53	.50	.48	.44	.48	.28
Sum	25.72	16.50	12.65	10.37	8.87	7.77	7.03	6.43	6.02	5.86	5.31	6.03	3.64
Mean	2.143	1.375	1.054	.864	.739	.647	.586	.536	.502	.488	.442	.502	.303
Mean.	1.953	1.260	.969	.800	.688	.605	.551	.508	.475	.469	.419	.498	.305

Hirn's Analysis Apr 1, 1901.

Condensing engine Form I.

Kind of engine - Hamilton Corliss, single cylinder

Length of stroke - 24"

Diam. of cylinder - $10\frac{3}{16}$"

Diam. of piston rod - 2"

Volume cylinder - Head 1.135 - Crank 1.090 - Mean 1.112

Volume clearance - " .0686 - " .0576 " .0631

Clearance in % of stroke 5.67%

Boiler pressure by guage 91.0 lbs

Barometer 29.96 ins 14.7 lbs per sq. in.

Boiler pressure, absolute 105.7 lbs.

Boiling temperature, atmospheric pressure 212°F.

Revolutions per hr. 9604

Steam used during run 561 lbs.

Quality of steam in steam pipe x = .99

Wt. of condensed steam per hr. 561 lbs.

Pounds of wet steam per stroke .0778 lbs.

Temperature condensed steam 119.3°F.

Temperatures condensing water, inflow 84.2°F.
outflow 104.5°F.

Pounds of condensing water per hr. 24900 lbs.

Pounds of condensing H_2O per revolution 6.90 lbs.

Cut off % of stroke – Head 5.88 – Crank 7.68 – Mean 6.78

Release " " – " 93.8 – " 94.5 – " 94.2

Compression " – " 9.69 – " 9.86 – " 9.78

Pounds of steam per I H P hr. 37.6 lbs.

Pounds of steam per B H P hr 38.3 "

Indicated horse power 16.08 H.P.

Brake horse power 14.53 H.P.

Form II.

	Head end			Crank end			Mean Ex. work.
	Mean Pressure	Ex. work Ft. lbs.	Ex. work B.T.U.	Mean Pressure	Ex. work Ft. lbs.	Ex. work B.T.U.	
Admission	102.0	982	1.26	105.5	1280	1.64	1.45
Expansion	32.4	4650	5.97	35.9	4920	6.32	6.15
Ex Lapse	8.15	1165	1.50	7.87	1160	1.49	1.50
Compression	19.8	313	.403	19.5	303	.389	.396

Form II continued.

	Cut off	Release	Compress.	Admission
Absolute pressure H	104.2	17.8	8.96	57.4
C	106.5	19.4	8.96	54.3
Mean	105.4	18.6	8.96	55.8
Heat of Liquid q	301.9	193.0	157.7	257.3
Internal Latent heat ρ	799.5	884.0	908.6	834.2
Latent heat evap. r	881.1	957.4	979.1	912.5
Total Heat	1183.0	1150.4	1139.3	1169.7
Vol. 1 lb. cu ft.	4.191	21.34	42.33	7.594
Volumes H	.1353	1.134	.1786	.0686
C	.1411	1.085	.1651	.0576
Mean.	.1382	1.110	.1719	.0631

Form no III.

Heat transfer per 100 strokes.

Steam from boiler, lbs.	9.78
Steam at admission, lbs.	.407
Steam, total, lbs.	8.187
Heat of condensed steam, B.T.U.	679
Condensing water, lbs.	345
Heat given to condensing water, B.T.U.	6980
Heat supplied to engine, B.T.U.	9150
Heat at admission, B.T.U.	1337
Heat at cut off, B.T.U.	5110
Heat at release, B.T.U.	6280
Heat at beginning of compression,	434
Cylinder loss during admission, B.T.U.	5232
Cylinder loss during expansion, B.T.U.	-1785
Cylinder loss during exhaust, B.T.U.	-1663
Cylinder loss during compression, ...	-863
Heat discharged and work	8229
Loss	921
Loss	921

Form no IV.

Summary and results.

Quality of steam entering,	per cent.	99.0
Quality of steam at cut off,	" "	40.4
" " "	" release, "	63.6
" " "	" compression, "	100.0
" " "	" admission, deg superheat	682°
Quality of steam in exhaust,	per cent	84.5
Heat lost, admission,	" "	57.3
Heat restored, expansion,	" "	19.5
Heat rejected, exhaust	" "	65.6
Heat gained, compression	" "	9.4
Heat Lost, radiation	" "	10.1
Heat utilized, work	" "	6.2
Ratio, radiation to work	" "	1.61
Ratio, cylinder condensation to work,		9.2
Carnot's efficiency		18.5
Thermodynamic efficiency		6.78
Actual efficiency		5.6
Eff. compared with ideal	per cent	30.3

Calculations of the foregoing results.

Quality of steam entering.

Pressure = 94.81 lbs, corrected = 91.0 lbs.

Absolute pressure = 105.7 lbs.

Exhaust pressure = 15.68 lbs.

$$q + xr = q_1 + r_1 + .48 (t_{sup} - t_{sat})$$

$$302.1 + x\ 881.0 = 184.0 + 963.5 + .48 (291.2 - 215.3)$$

T for 105.7 lbs. = 331.6°

Upper thermom. = 324.6

Correction = 7.0

Lower thermom = 284.2

T_{sup} = 291.2° F

$$881 x = 881.8$$

$$x = 1+$$

The steam is superheated in the heat gauge, but may be considered practically dry.

Wt of steam through gauge = 61.9 #

Wt of water in drip pot = .632 #

$$\% \text{ moisture} = \frac{.632}{61.9 + .632}$$

$$= .0101$$

$$x = 1.00 - .01 = .99$$

Pounds of condensing water.

Hook gauge = 12.39 − 10.946 = 1.444 ins = .12 ft.

Width of weir = 10 ins = .833 ft.

Temp = 102.2° F

Wt. per cu ft = 62.0 lbs from Kent.

Francis formula

$$Q = 3.33(l - .2h)h^{\frac{3}{2}}$$

$$= 3.33(.833 - .2 \times .12).12^{\frac{3}{2}} \text{ cu ft per sec}$$

$$= 3600 \times 62 \times 3.33 \times .809 \times .12^{\frac{3}{2}}$$

$$= \underline{24900} \text{ lbs per hr.}$$

Indicated horse power.

M.E.P = 27.51 lbs per sq in

Stroke = 24"

Mean piston area = 80.4

Revolutions per hr = 3604

$$IHP = \frac{27.51 \times 2 \times 80.4 \times 3604 \times 2}{33000 \times 60}$$

$$= \underline{16.08} \text{ H.P.}$$

Brake horse power Arm = 3.6 ft.

$$BHP = \frac{352 \times 27 \times 3.6 \times 3604}{33000 \times 60} = \underline{14.53}$$

Steam per I.H.P. hr.

Total steam = 561 lbs x = .99

I.H.P = 16.08.

water rate = $\frac{.99 \times 561}{16.08}$ = 37.6 lbs

Steam at admission

Volume at compression = .179 cu. ft.

Assume x = 1 at beginning of compression

V = m x s 100 strokes.

m = $\frac{V}{x s}$ = $\frac{.179 \times 100}{1 \times 42.33}$ = .407 lbs

---

Heat of condensed steam

Temperature = 119.3° F q = 87.3

Heat = 1.78 x 87.3 = 679 B.T.U.

Heat given to condensing water.

Inflow = 84.2° F q = 52.27

Outflow = 104.5° F q = 72.5

Heat = 345 (72.5 − 52.27) = 6980 B.T.U.

Heat supplied to engine

= W(q + x r) = 9150 B.T.U.

Heat at cut off. 8.19 lbs. of steam

Heat = $M(g + xp)$ $M_x = \frac{V}{v}$

$= 8.19 \times 301.9 + \frac{13.82}{4.191} \times 799.5$

$= 5110$ B.T.U.

The calculations for release, compression and admission are similar to the above.

Cylinder loss during admission

Heat at admission + Heat added =

Work + Heat at cut off + Cylinder Loss.

loss = 1337 + 9150 − 145 − 5110

= 5232 B.T.U.

Cylinder loss during exhaust.

Heat at release = 6280

Work = 150

6350

Heat at compression = 434

Heat in condensing 406900

Heat in condensed steam 679

8093

6430

Gain = 1663 B.T.U.

Quality of steam in exhaust

$$\text{Heat} = M(q + x r)$$

$$x = \frac{\frac{\text{Heat}}{M} - q}{r}$$

$$= \frac{\frac{6980}{7.78} - 151.5}{986.2}$$

$$= \underline{54.5\ \%}$$

Carnot's efficiency

J at 103.2 lbs	=	329.76
J " 8.01 "	=	182.97
		146.79

$$E = \frac{146.79}{329.7 + 460.7}$$

$$= \underline{18.5\ \%}$$

Actual efficiency $\qquad$ BHP = 14.53

$$E = \frac{14.53 \times 33000 \times 60 \times 100}{778 \times 9150 \times 3604 \times 2}$$

$$= \underline{5.6\ \%}$$

A number of the calculations were omitted, as they were so extremely simple, that it was not considered necessary to give them.

Test no 2. Non-Condensing. May 13, 1901.

Observations.

Time	Condenser. Temperatures: Con. Steam	Outflow	Inflow	Hook Gauge	Temp. of weir	Calorimeter: Pressure	Upper Ther.	Lower Ther	Hg. Column: Left	Rt.
3.20	105.0	81.5	100	10.99	100.	96	327.6	280.6	4.55	9.05
3.25	107.8	82.2	102	11.00	100.1	96	328	280.9	4.50	9.10
3.30	108.0	82.3	101.9	11.00	101.3	96	328	280.6	4.53	9.08
3.35	107.9	84.0	102.	11.02	102.0	95.5	327.9	281.0	4.55	9.05
3.40	110.	84.2	103.6	11.02	102.6	95.	327.0	280.0	4.55	9.05
3.45	110.	85.0	104.4	11.02	104.0	94.8	327.0	280.0	4.55	9.05
3.50	111.	88.2	105.9	11.02	104.9	92.5	322.6	282.0	4.60	9.00
3.55	112.	88.0	106.	11.02	106.	93.0	322.	282	4.58	9.04
4.00	112.1	88.0	106.9	11.02	106.7	94.4	324	283	4.53	9.01
4.05	112.6	89.2	108.0	11.02	107.8	96.5	322	281.6	4.50	9.10
4.10	112.6	90.0	109.3	11.02	108.4	97.7	326	283.0	4.48	9.12
4.15	114.5	90.6	110.	11.02	109.8	98.	326	284.	4.40	9.15
4.20	115.9	91.1	110.	11.02	110.0	97.5	325.9	283.1	4.42	9.14
Sum	1442.4	1124.3	1370.0	143.19	1363.6	1242.9	4234.0	3661.8	58.74	118.00
Mean.	110.9	86.5	105.4	11.01	104.9	95.6	325.7	281.7	4.52	9.08

Condensed Steam: Time	Wt. emp.	Wt. full	Drip pot: Time wt.	Wt. emp.	Wt. full
3.20	93.5	238.0	3.20	1-0-7	1-1-6
3.35	211.5	350.0	3.59	1-0-0	1-1-4
3.50	238.0	360.0	4.20		
4.05	350.0	490.0			
4.20					
Sum.	893.0	1443.0		2-0-7	2-11-10
Mean		350			0-11-3

Bucket: Time	Wt. emp.	Wt. full	Counter: Time	Reading
3.20	3-13-12	20-6-14	3.20	7921
3.36	2-14-9	18-7-2	3.35	5808
3.51	3-13-10	23-10-2	3.50	9696
4.10	2-14-9	13-5-4	4.05	0585
4.20			4.20	1475
	13-8-8	75-13-6		
		62-4-14		3554

Brake reading 373.5# zero 107.5# Diff = 266#

Zero reading of hook gauge = 12.41"

Zero reading of Hg column left 7.00 Rt. 7.05

Barometer = 29.87 inches.

Cards were taken every five minutes.

Preliminary work on cards.

No.	Area. Head	Area. Crank	Length	M.E.P. Head	M.E.P. Crank.
1	1.54	1.89	3.44	18.00	22.05
2	1.62	2.18	3.43	19.00	25.5
3	1.66	2.03	3.44	19.4	23.7
4	1.48	1.98	3.43	17.33	23.25
5	1.46	2.09	3.43	17.1	24.5
6	1.76	1.84	3.41	20.75	21.7
7	1.78	1.95	3.42	20.9	22.9
8	1.72	1.89	3.42	20.3	22.2
9	1.71	1.95	3.42	20.1	22.9
10	1.45	1.67	3.36	17.33	20.0
11	1.65	2.01	3.39	19.55	23.8
12	1.76	1.94	3.39	20.9	23.0
13	1.64	1.84	3.38	19.5	21.9
			44.36	250.16	297.40
			3.412	19.24	22.86

21.05

Mean values of cut off, etc.

No	Ordinates: Admission H	Admission C	Cut off H	Cut off C	Release H	Release C	Compress. H	Compress. C	Abscissae: Cut off H	Cut off C	Release H	Release C	Compress. H	Compress. C
1	1.53	2.45	2.69	2.67	.51	.52	.44	.43	.16	.23	3.21	3.31	.29	.33
2	1.56	2.35	2.67	2.65	.52	.53	.42	.38	.19	.24	3.20	3.25	.24	.34
3	1.33	2.22	2.67	2.68	.50	.52	.41	.41	.17	.25	3.19	3.30	.27	.34
4	1.57	2.19	2.68	2.65	.48	.51	.42	.39	.15	.24	3.20	3.26	.27	.34
5	1.38	2.17	2.63	2.65	.46	.53	.41	.39	.15	.28	3.23	3.28	.28	.34
6	1.45	2.13	2.59	2.62	.49	.48	.40	.40	.20	.23	3.20	3.27	.29	.33
7	1.51	2.08	2.56	2.58	.52	.51	.40	.40	.22	.25	3.20	3.28	.27	.36
8	1.40	2.02	2.58	2.57	.50	.50	.39	.38	.20	.24	3.21	3.30	.33	.41
9	1.43	1.83	2.60	2.60	.50	.51	.41	.40	.20	.25	3.22	3.27	.29	.35
10	1.49	1.86	2.66	2.68	.49	.48	.40	.40	.11	.22	3.15	3.22	.29	.37
11	1.21	2.31	2.71	2.73	.50	.52	.42	.40	.17	.22	3.17	3.26	.29	.36
12	1.39	2.18	2.70	2.73	.51	.49	.40	.40	.18	.22	3.16	3.23	.28	.36
13	1.32	2.06	2.74	2.74	.50	.50	.41	.39	.16	.19	3.16	3.22	.30	.36
Sum	18.57	27.85	34.48	34.55	6.48	6.60	5.33	5.17	2.26	3.06	41.50	42.45	3.69	4.59
Mean	1.430	2.143	2.652	2.658	.498	.508	.410	.398	.174	.235	3.192	3.265	.284	.353
	71.8		106.7		20.2		16.2		6%		94.6%		94%	

Measurements for external work.

No.	Head.						Crank.					
	Admission			Expansion			Admission			Expansion		
	R_1	R_2	Area	R_1	R_2	Area	R_1	R_2	Area	R_1	R_2	Area
1	1074	1113	.39	1113	1380	2.67	9990	0050	.60	0050	0334	2.84
2	2458	2505	.47	2505	2761	2.56	2059	2135	.76	2135	2419	2.84
3	3751	3796	.45	3796	4056	2.60	4693	4760	.67	4760	5051	2.91
4	5110	5152	.42	5152	5409	2.57	4734	4800	.66	4800	5080	2.80
5	5849	5883	.34	5883	6135	2.52	5414	5495	.81	5495	5773	2.78
6	7362	7408	.46	7408	7667	2.59	7145	7203	.58	7203	7481	2.78
7	8358	8414	.56	8414	8681	2.67	7992	8055	.63	8055	8333	2.78
8	9615	9666	.51	9666	9922	2.56	9393	9463	.70	9463	9734	2.71
9	0294	0347	.53	0347	0610	2.63	0108	0179	.71	0179	0450	2.71
10	1383	1413	.30	1413	1661	2.48	1092	1145	.53	1145	1402	2.57
11	2250	2302	.52	2590	2845	2.55	2178	2241	.63	2241	2520	2.79
12	3884	3932	.48	3932	4194	2.62	3354	3612	.58	3612	3885	2.73
13	4507	4551	.44	4551	4810	2.59	4081	4135	.54	4135	4406	2.71
			5.87			33.61			8.40			35.95
			.452			2.585			.646			2.765
	Exhaust			Compression			Exhaust			Compression		
1	2477	2600	1.23	2600	2620	.20	0316	0442	1.26	0442	0468	.26
2	3915	4041	1.26	4041	4055	.14	2302	2411	1.09	2411	2437	.26
3	4455	4576	1.21	4576	4593	.17	4610	4730	1.20	4730	4760	.30
4	5647	5770	1.23	5770	5789	.19	5726	5244	1.18	5244	5272	.28
5	6504	6627	1.23	6627	6643	.16	5790	5913	1.23	5913	5941	.28
6	7880	7996	1.16	7996	8015	.19	7296	7414	1.18	7414	7441	.27
7	9213	9335	1.22	9335	9346	.11	8502	8620	1.18	8620	8645	.25
8	0007	0119	1.12	0119	0142	.23	9544	9655	1.11	9655	9683	.28
9	0931	1047	1.16	1047	1066	.19	0440	0557	1.17	0557	0579	.22
10	2068	2172	1.04	2172	2198	.26	1327	1435	1.08	1435	1465	.30
11	3366	3481	1.15	3497	3617	.20	2498	2617	1.19	2617	2647	.30
12	4389	4451	1.12	4451	4469	.18	3814	3927	1.13	3927	3954	.27
13	4890	5005	1.15	5005	5023	.17	4251	4364	1.13	4364	4392	.28
			15.28			2.39			15.13			3.55
			1.175			.184			1.164			.273

Data for mean card.

	No.	Expansion									Exhaust		Compression	
		1	2	3	4	5	6	7	8	9	1	2	1	2
Head	1	1.55	1.11	.91	.77	.67	.62	.57	.55	.52	.50	.46	.67	.46
	2	1.62	1.13	.90	.79	.70	.64	.59	.56	.55	.52	.46	.63	.42
	3	1.65	1.14	.90	.76	.68	.62	.57	.54	.52	.50	.46	.64	.45
	4	1.59	1.11	.88	.75	.66	.61	.56	.52	.50	.48	.44	.70	.45
	5	1.53	1.08	.84	.72	.64	.58	.55	.51	.50	.48	.43	.67	.45
	6	1.72	1.16	.92	.78	.68	.61	.57	.53	.51	.50	.44	.66	.48
	7	1.77	1.18	.94	.79	.70	.63	.59	.55	.53	.52	.47	.70	.50
	8	1.73	1.17	.92	.78	.69	.62	.59	.55	.52	.51	.45	.71	.45
	9	1.77	1.15	.93	.78	.70	.62	.57	.55	.52	.50	.44	.66	.44
	10	1.47	1.02	.83	.72	.65	.59	.54	.51	.49	.49	.45	.71	.46
	11	1.72	1.15	.92	.79	.69	.61	.58	.55	.53	.50	.45	.72	.48
	12	1.77	1.18	.93	.79	.70	.63	.58	.54	.52	.51	.46	.65	.44
	13	1.66	1.14	.91	.77	.69	.62	.57	.53	.52	.50	.45	.70	.46
	Sum	21.55	14.72	11.73	9.99	8.85	8.00	7.43	6.99	6.73	6.51	5.86	8.82	5.94
	Mean	1.66	1.13	.902	.768	.681	.615	.572	.538	.518	.501	.451	.679	.457
Crank	1	1.97	1.36	1.10	.92	.78	.70	.64	.59	.56	.55	.53	.86	.59
	2	2.22	1.48	1.15	.94	.82	.72	.65	.60	.56	.54	.53	.91	.57
	3	2.06	1.43	1.13	.94	.80	.71	.65	.59	.55	.54	.53	.86	.58
	4	2.03	1.38	1.11	.91	.77	.69	.62	.57	.53	.52	.50	.85	.56
	5	2.11	1.46	1.13	.95	.80	.73	.65	.60	.55	.54	.52	.87	.58
	6	1.95	1.80	1.03	.87	.75	.66	.60	.55	.58	.49	.47	.86	.55
	7	2.07	1.41	1.09	.90	.77	.68	.61	.56	.53	.50	.49	.84	.56
	8	1.91	1.34	1.05	.89	.76	.67	.60	.56	.52	.51	.49	.83	.57
	9	2.05	1.37	1.07	.90	.77	.68	.63	.58	.53	.52	.49	.89	.59
	10	1.75	1.18	.93	.80	.72	.65	.58	.54	.50	.49	.46	.85	.58
	11	2.06	1.38	1.09	.93	.80	.71	.64	.59	.55	.54	.50	.84	.58
	12	2.01	1.37	1.07	.92	.78	.68	.61	.55	.52	.50	.48	.85	.55
	13	1.94	1.32	1.04	.87	.73	.68	.61	.57	.53	.52	.50	.86	.59
	Sum	26.19	18.28	13.99	11.74	10.05	8.96	8.09	7.45	6.93	6.76	6.49	11.17	7.47
	Mean	2.01	1.41	1.08	.903	.773	.689	.622	.573	.533	.520	.499	.859	.575
	Mean	1.84	1.27	.99	.84	.73	.65	.60	.55	.53	.51	.48	.77	.52

Hirn's Analysis May 13, 1901.

Non-Condensing engine Form I.

Kind of engine - Hamilton Corliss - single cylinder.

Length of stroke - 24"

Diam of cylinder - $10\frac{3}{16}$"

Diam. of piston rod - 2"

Volume cylinder - Head - 1.135 - Crank - 1.090 - Mean 1.112

Volume clearance - " .0686 - " .0576 - " .0631

Clearance in % of stroke 5.67%

Boiler pressure by gauge 92.1 lbs.

Barometer 29.87 ins 14.66 lbs per sq in

Boiler pressure, absolute 106.8 " " " "

Boiling temp, atmospheric pressure 211.8° F.

Revolutions per hr. 3535-4.

Steam used during run 5550 lbs.

Quality of steam in steam pipe x = .989

Wt. of condensed steam per hr. 5550 lbs.

Pounds of wet steam per stroke .0772 lbs

Temperature condensed steam 110.9° F

Temperature condensing water, inflow 86.5° F,
outflow 105.4° F.

Pounds of condensing water per hr. 23900

Pounds of condensing water per revolution, 6.73

Cut off % of stroke - Head 5.10 - Crank 6.89 - Mean 6.00.

Release " " " 93.6 - " 95.7 - " 94.6.

Compression " - " 8.34 - " 10.35 - " 9.40.

Pounds of steam per I.H.P. hr. 45.4

Pounds of steam per B.H.P. hr. 51.2.

Indicated horse power 12.10

Brake horse power. 10.75

Form II

	Head			Crank.			Mean Ext. work.
	Mean Pressure	Ext. work Ft. lbs.	Ext. work B.T.U.	Mean Pressure	Ext. work Ft. lbs.	Ext. work B.T.U.	
Admission	104.2	871	1.12	110.5	1200	1.54	1.33
Expansion	34.4	4990	6.41	36.7	5140	6.60	6.51
Ex Lower	13.8	2260	2.91	13.7	2165	2.78	2.85
Compression	26.1	355	.459	31.1	507	.651	.555

Form no II, continued.

	Cut off	Release	Compression	Admission
Absolute pressure, lbs.	106.7	20.2	16.2	71.8
Heat of Liquid q	302.9	197.4	185.7	273.9
Internal Latent heat	199.0	880.6	889.5	821.4
Latent heat evap. r	880.5	973.2	962.3	900.9
Total heat	1183.3	1171.7	1148.1	1174.8
Vol. 1 lb. cu ft.	4.143	19.73	24.32	6.000
Volumes H	.1266	1.131	.1632	.0686
C	.1326	1.100	.1703	.0576
Mean	.1296	1.115	.1667	.0631

Form no III.

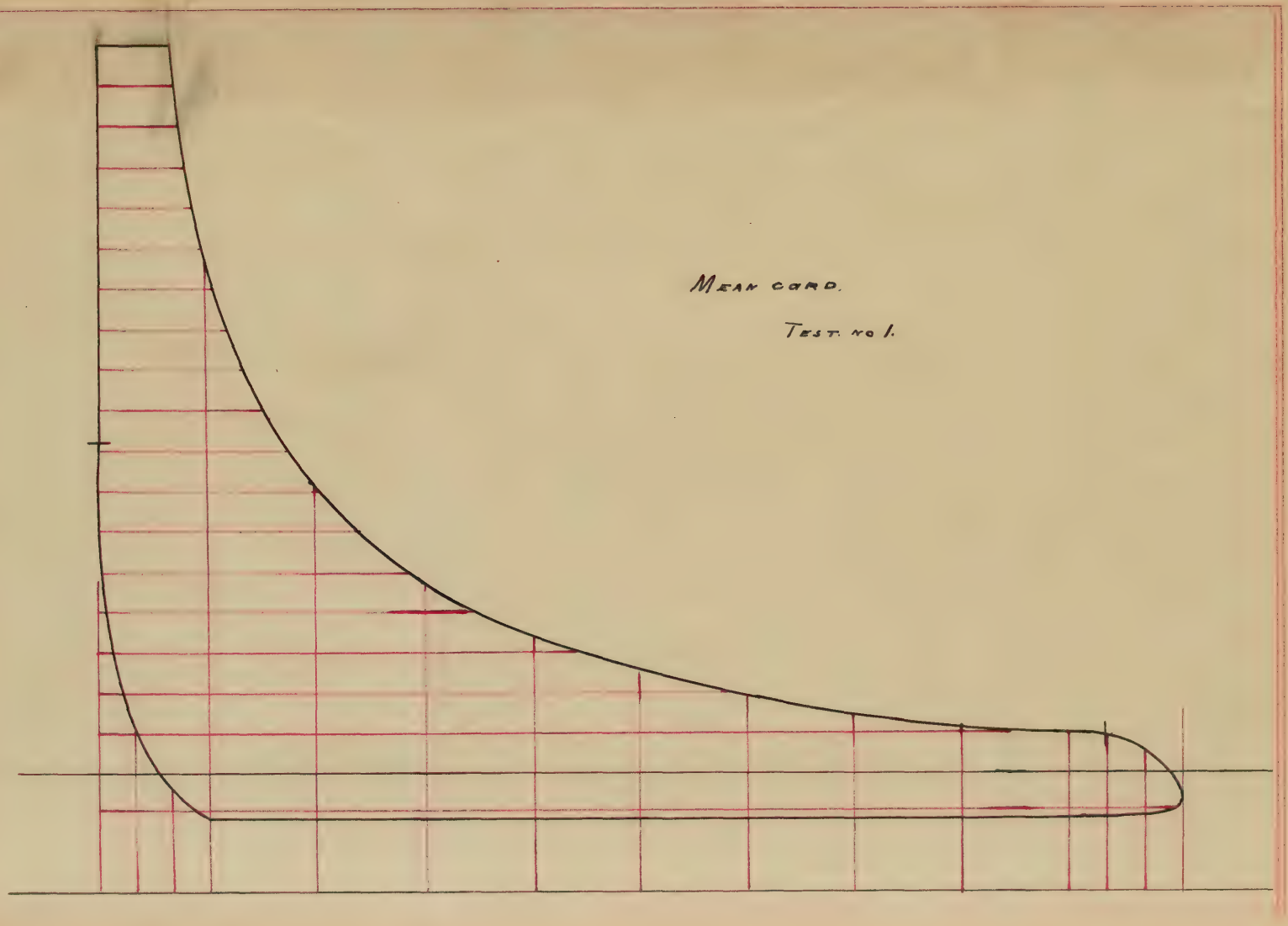
Heat transfer per 100 strokes.

Steam from boiler, lbs.	7.72
Steam at admission, lbs.	.686
Steam, total, lbs	8.406
Heat of condensed steam, B.T.U.	610
Condensing water, lbs.	336.5
Heat given to condensing water, B.T.U.	6340
Heat supplied to engine, B.T.U.	9050
Heat at admission, B.T.U.	866
Heat at cut-off, B.T.U.	5060
Heat at release, B.T.U.	6640
Heat at beginning of compression	736
Cylinder loss during admission	4723 B.T.U.
Cylinder loss during expansion	− 2231 " "
Cylinder loss during exhaust	− 761 " "
Cylinder loss during compression	− 75 " "
Heat discharged and work.	7394 " "
Loss	1656 " "
Loss	1656 " "

Form no IV.

Summary and results.

Quality of steam entering	98.9 per cent.
" " at cut off	37.2 " "
" " release	67.1 " "
" " compression	100.0 " "
" " admission	355° superheat
" " in exhaust	74.3 per cent.
Heat lost, admission,	52.1 " "
Heat restored, expansion	24.6 " "
Heat rejected, exhaust	68.4 " "
Heat gained, compression	.8 " "
Heat lost, radiation	18.3 " "
Heat utilized, work	4.9 " "
Ratio, radiation to work	3.73
Ratio, cylinder condensation to work	10.6
Carnot's efficiency	17.6 per cent.
Thermodynamic efficiency,	5.13 " "
Actual efficiency,	4.25 " "
Eff. compared with ideal	29.1 " "


MEAN CORD.
TEST. NO 1.

MEAN CARD.
TEST NO. 2.

Arranged by Sidney A. Reeve, M.E.

Entropy-temperature Diagram-blank for Steam-engines.

EXPLANATORY PAMPHLET PUBLISHED SEPARATELY

EXTRA COPIES OF THIS DIAGRAM MAY BE OBTAINED AT A COST OF 25¢ EACH BY ADDRESSING PROGRESSIVE AGE PUBLISHING COMPANY, 280 BROADWAY, N.Y.

Entropy-temperature Quadrant.

Area-scale in this quadrant:
1 square twenty-fourth inch = 0.01 B.t.u. = 7.78 ft.lbs.
1 square inch = 5.76 B.t.u. = 1331.28 ft.lbs.

N.B. ALL SCALES MAY BECOME INCORRECT FROM SHRINKAGE OF PAPER. WORK TO SCALES ON AXES.

Saturated steam.

Water

Temperature axis. 350° Fahrenheit. 300° 250° 200° 150°

Scale, ⅛" = 1° F.

Entropy axis.
Scale, ⅛" = 0.01 unit.

2.00
1.50
1.00
0.50
100
150
50

Temperature-pressure Quadrant.

Saturated steam.

1.0 lb. 0.9 lb. 0.8 lb. 0.7 lb. 0.6 lb. 0.5 lb. 0.4 lb. 0.3 lb. 0.2 lb. 0.15 lb. 0.10 lb. 0.07 0.05 0.03 0.02 0.01 0.005 lb.

100 – % steam.
99 – " "
98 – " "
97 – " "
96 – " "
95
94
93
92
91
90
89
88

Pressure axis.

Entropy-volume Quadrant.

–2 lb. 205¼° Volume, ½-scale.
–8 lb. 175° volume, ½-scale.
–6 lb. 191.8° volume, ½-scale.
–10 lb. 159.7° volume, ½-scale.
–12 lb. 137.6° volume, ½-scale.

Engine: Hamilton Corliss
Date of test: Apr 1, 1901
General conditions: Condensing
Condition of steam: x = .99
Feed-water per I.H.P. per hour: 37.6
Revolutions per minute: 60.6 ; per 1 lb. feed-water: 6.5

Cylinders:

	High-press.	1st Interm.	2nd Interm.	Low-press
Number:	one			
Diameter:	10½ in.	in.	in.	in.
Stroke:	24" in.	in.	in.	in.
Percentage of clearance:	5.67			
Mean effective pressure:	27.5 lbs.	lbs.	lbs.	lbs.
Indicated horse-power:	16.08			
Piston-displacement per 1 lb. of fed	14.46 cu.ft.	cu.ft.	cu.ft.	cu.ft.
Cushion-steam " " " by weight:	.0528 lbs.	lbs.	lbs.	lbs.
Volume-scale of indicator-card	1" = 55.20""			

Volume axis
Scale, ⅛" = 0.1 cu. ft.

Entropy account:

Work theoretically available per 1 lb. of feed:	173.3 ~~ft.lbs.~~ B.t.u.			
Work actually developed " " " " , by indicator:	75.9			ft.lbs.
" " " " " " , " entropy-diagram:	72.3			"
Loss from wire drawing:	0			"
" " initial condensation:	56.1.0			"
" " condensation during expansion:	25.6			"
Gain " re-evaporation " " :	249.9			"
Loss " incomplete expansion:	358.0			"
" " clearance:	7.3			"
" " back-pressure:	—			"
Receiver-losses; first:	second:	third:		"
Algebraic sum of losses and gains	70.2			

5 cu.ft. 10 15 20 25

Volume-pressure Quadrant.

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Arranged by SIDNEY A. REEVE, M.E.

ENTROPY-TEMPERATURE DIAGRAM-BLANK FOR STEAM-ENGINES.

EXPLANATORY PAMPHLET PUBLISHED SEPARATELY.

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Entropy-temperature Quadrant.

Area-scale in this quadrant:
1 square twenty-fourth inch = 0.01 B.t.u. = 7.78 ft.lbs.
1 square inch = 5.76 B.t.u. 4481.28 ft. lbs.

N.B. ALL SCALES MAY BECOME INCORRECT FROM SHRINKAGE OF PAPER. WORK TO SCALES ON AXES.

Entropy axis
Scale, 1/8 = 0.01 unit.

2.00
1.50
1.00
0.50

Saturated steam.

Water.

Temperature axis. 350° Fahrenheit.
Scale, 1/8 = 1° F.

300° 250° 200° 150°

Temperature-pressure Quadrant.

Saturated steam.

100 – % steam.
99 – " "
98 – " "
97 – " "
96 – " "
95 –
94 –
93 –
92 –
91 –
90 –
89 –
88 –

1.0 lb. 0.9 lb. 0.8 lb. 0.7 lb. 0.6 lb. 0.5 lb. 0.4 lb. 0.3 lb. 0.2 lb. 0.15 lb. 0.1 0.07 0.05 0.03 0.01

Scale, 1/8 = 1 lb. pressure.

Pressure axis.

150
100
50
0

Cylinders:

Number: one

	High-press.	1st Interm.	2nd Interm.	Low-press.
Diameter:	10 1/2 in.	in.	in.	in.
Stroke:	24 in.	in.	in.	in.
Percentage of clearance:	5.67			
Mean effective pressure:	21.05 lbs.	lbs.	lbs.	lbs.
Indicated horse-power:	12.10			
Piston-displacement per 1 lb. of feed	14.53 cu ft.	cu ft.	cu ft.	cu ft.
Cushion-steam " " " " by weight:	.0892 lbs.	lbs.	lbs.	lbs.
Volume-scale of indicator-card:				

Entropy account:

Work theoretically available per 1 lb. of feed:	142 B.T.U. ft.lbs.
Work actually developed " " " " , by indicator:	55.7 ft.lbs.
" " " " " " " , " entropy-diagram:	57.8 "
Loss from wire drawing:	0 "
" " initial condensation:	616.0 "
" " condensation during expansion:	35.8 "
Gain " re-evaporation " "	34.3 "
Loss " incomplete expansion:	9.0 "
" " clearance:	3.85 "
" " back-pressure:	4.36 "
Receiver-losses: first: — second: — third: —	
Algebraic sum of losses and gains:	

Entropy-volume Quadrant

–2 lb. 205 1/4° Volume, 1/8-scale
–4 lb. 175° volume, 1/8-scale
–6 lb. 161.6° volume, 1/8-scale
–10 lb. 159.7° volume, 1/8-scale
–12 lb. 137.6° volume, 1/8-scale

Engine: Hamilton Corliss
Date of test: May 13, 1901
General conditions: Non-Condensing
Condition of steam: x = .969
Feed-water per I.H.P. per hour: 15.4
Revolutions per minute: 59 1/2 ; per 1 lb. feed-water: 6.5

Volume axis
Scale, 1/8 = 0.1 cu ft.

Saturated steam.

5 cu ft. 10 15 20 25

Volume-pressure Quadrant.

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Comparison of the two methods.

	Apr 1.		May 13.	
Losses	Hirn	Reeve	Hirn	Reeve
Admission	673	561	611	616
Expansion	-230	-224	-289	-308.5
Exhaust.	-214	-358	-98.5	-97.0
Compression	-111	——	-9.7	——

The above table shows the agreement between the results of the two analyses. In some cases it is close, and in others, not so close. It is perhaps not well to compare the losses during the exhaust at all, as in Reeves analysis, the exhaust curve is assumed, and in Hirn's analysis some of the factors are not perfectly definite. As far as accuracy goes, there is not very much choice between the two, for both have their faults. Still, strict

accuracy is not what is desired in this case, but just an estimate of the distribution of the losses. There are some objections to the theory of Hirn's analysis These are explained in A.S.M.E. V XII p 790.

As far as convenience goes, Reeves analysis is by far the better of the two, as results of equal accuracy are obtained in much less time, and with much less work. In some cases, with bad cards, it becomes rather difficult to puzzle out the losses, but in most cases, it is entirely possible. When certain changes are to be made in an engine, this method is very valuable, because without this diagram only one change could be made at a time, and an efficiency test would have to be made after each.

When the curves may be obtained already prepared, the entropy method

is by far the easier, and should always be used.

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